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OPERATIONAL EFFECTS OF RTOR IN NEW JERSEY

BY

WILLIAM L. MULLOWNEY
PRINCIPAL ENGINEER

AND

THOMAS D. DAVIS
SENIOR ENGINEER

BUREAU OF TRANSPORTATION SYSTEMS RESEARCH
DIVISION OF RESEARCH AND DEMONSTRATION
NEW JERSEY DEPARTMENT OF TRANSPORTATION

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16. Abstract

This study was conducted to measure the effects Right Turn on Red (RTOR) had on delay and accidents at signalized intersections in New Jersey. Since its implementation in January 1977, stopped vehicles saved an average of 3.0 seconds/vehicle and approach vehicles saved an average of 1.4 seconds/vehicle. Five percent of the pedestrians were delayed in some manner by RTOR vehicles. The accidents were studied by comparing the change in accidents at test intersections which allowed RTOR at all approaches with the change in accidents at control intersections which prohibited RTOR. RTOR caused a significant increase in accidents at intersections which involved a state highway. During the period 1978-1981, approximately 3,000 accidents/year were caused by the allowance of RTOR. No change in accidents was found at intersections involving only county and/or local roads over the same time period.

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TABLE OF CONTENTS

	Page
List of Tables	v
List of Figures	vi
Summary and Conclusions	1
Introduction	3
Traffic Performance Studies	5
Study Procedure	5
Results	10
Comparisons With Other Studies	23
Estimation of Reduced Gasoline Usage and Pollutant Levels Due to RTOR	25
Discussion of Results	27
Accident Studies	29
Review of Past Literature	29
Study Design	33
Discussion of Factors Which May Bias the Data	36
Results	40
Estimation of Accidents Caused by RTOR	51
Cost Benefit Analysis of RTOR in New Jersey	53
Discussion and Further Research	58
References	63
Acknowledgements	65

LIST OF TABLES

Table		Page
1	Site Descriptions	7
2	RTOR and NTOR Data	11
3	Vehicle Delay Savings with RTOR	19
4	Pedestrian Delay	22
5	Results of Accident Analyses - All Intersections	42
6	Results of Accident Analyses - State Highway Intersections	44
7	Results of Accident Analyses - State Highway Intersections by Time Period	46
8	Results of Accident Analyses - State Highway Intersection by Time Period	47
9	Accidents per Intersection by Road Type	52

LIST OF FIGURES

Figure		Page
1	RTOR and NTOR Violation Rates	12
2	Motorist Conformance to RTOR Signs - AM, Peak	14
3	Motorist Conformance to RTOR Signs - Off Peak	15
4	Motorist Conformance to RTOR Signs - Off Peak	16
5	Motorist Conformance to RTOR Signs - PM, Peak	17
6	Vehicle Delay Savings	18
7	Delay Savings with RTOR	21
8	Yearly Accidents per Intersection by Road Type	49
9	Change in Yearly Accidents per Intersection	50

SUMMARY AND CONCLUSION

This study measured the effects Right Turn on Red (RTOR) had on delay and accidents at signalized intersections in New Jersey since it became a law on January 2, 1977.

Delay changes were determined by restricting RTOR at intersections that previously allowed RTOR. Five intersection approaches were selected in CBD, urban, suburban and rural areas where different degrees of pedestrian activities occurred. Peak and off-peak periods were considered.

Delay savings were measured with the stopped time delay technique. Stopped vehicles saved an average of 3.0 seconds/vehicle and approach vehicles saved an average of 1.4 seconds/vehicle when RTOR was permitted. Both savings were significant at the 95 percent confidence level. Five percent of the pedestrians crossing the approaches were delayed in some manner by RTOR vehicles. When RTOR was permitted, 26 percent of the right turn (11 percent of the approach) motorists made RTOR, but 40 percent of the RTOR drivers failed to come to a full stop before turning. When RTOR was restricted, six percent of the right turning (two percent of the approach) drivers turned on red. This drop in utilization was manifest just two months after the signs were installed but was still higher than the violation rate of 1.5 percent for right turns (0.3 percent of approach traffic) which exists at approaches that always prohibited RTOR.

The accidents were studied by comparing the change in accidents at test intersections which allowed RTOR at all approaches after 1977 with the change in accidents at control intersections which always prohibited RTOR.

The Chi-Square Test of Independence was used to determine significant changes. Accidents were classified into: accident type, severity, pre-accident vehicle action, peak and off-peak occurrence, and type of road.

RTOR caused a large accident increase at intersections involving state highways. Perhaps this increase was due to the fact that state roads have, on the average, more lanes, more traffic, and higher vehicle speeds than county and local roads. The accident increase included injury, PDO, angle and same direction accidents mainly in the off-peak period.

RTOR caused about 3,000 accidents per year between 1978-1981. However, the accident increases were greatest in the earlier years (1978 and 1979). This suggests that drivers are becoming accustomed to the RTOR maneuver.

INTRODUCTION

Right Turn on Red (RTOR) at signalized intersections remains a controversial issue in the domain of Traffic Engineering. Allowing RTOR was expected to result in less gasoline usage and lower pollutant levels associated with the operation of motor vehicles by reducing unnecessary idling time at signalized intersections. One of the arguments against RTOR was that while it decreased delay to motorists, it would increase delay to pedestrians by preventing them from crossing on the green signal. It has also been suggested that motorists do not obey the provision in the RTOR law which requires a full stop. Violations of NTOR signs may also be a problem. Some traffic engineers feel that the weakening of the authority of a traffic signal evidenced by such violations may result in a tendency on the motorists' part to disregard other traffic control devices.

Early reports on the subject of the RTOR-accident relationship found that a very small amount of minor accidents could be associated with allowing RTOR [1,2,3]. More recently, a number of reports have challenged this view, finding that RTOR can indeed result in sizable accident increases involving vehicles, pedestrians and/or bicycles [4,5,6,7,8]. This anti-RTOR view was countered by several other reports which produced new evidence showing that RTOR causes little or no problem and which cited inadequacies in the designs of the opposing studies suggesting their results and conclusions are unjustified [9,10,11,12].

Right Turn on Red can very easily become an emotional issue with concern for the safety of children and the elderly on one side and the need to

conserve energy and save time on the other. Because the question does involve safety, at least theoretically, it is imperative that any decisions made about where and when to employ RTOR as a time and fuel saving strategy be based on good foundations, that is, on well thought out and executed research studies.

The purpose of this project was to provide just such a well thought out and executed research study on the effects, if any, of RTOR at signalized intersections in New Jersey. Hopefully, the results will help traffic engineering decide where RTOR can achieve its desired goals without compromising safety at intersections. No attempt will be made to expand the results of this study countrywide and the reader is cautioned against assuming the results of this study apply elsewhere. New Jersey is a highly urbanized, densely populated state whose roads carry far greater than the average amount of traffic. The assumption that New Jersey is a typical state in how RTOR might affect accidents may not be valid.

This paper will detail how the design of the study came about and how inevitable compromises in the desired study design were necessitated by constraints of funding and the lack of certain information. It will discuss how the data and conclusions might be biased by deviations from the study design. Finally, the results and the conclusions drawn from these findings will be presented.

TRAFFIC PERFORMANCE STUDIES

Study Procedure

Select Intersections

Five intersection approaches were selected based on:

1. RTOR condition
2. Population density
3. Land use
4. Intersection geometrics
5. Pedestrian and vehicle volumes
6. Percent right turn movements

The intersections were in CBD, urban, suburban and rural areas where different degrees of pedestrian activity occurred. All the intersections were to be four legged with no dividers, one-way streets or left-turn arrows. Originally, an attempt was made to perform the delay studies at intersections which were undergoing a change in RTOR condition through the normal procedure used by the Bureau of Traffic Engineering. Data would be collected before and after the change in the RTOR condition was performed. Although such changes were common during the years immediately following the implementation of RTOR, by 1981-82 few changes were occurring. Consequently, the first half of 1982 yielded no intersections which had the necessary characteristics for study. A second method was then decided upon. Intersections with the desired characteristics were located through field surveys, being careful to select only approaches where RTOR was permitted. Data were collected under this condition. Then, a NTOR sign was

erected, and data were collected again under the RTOR prohibited condition. Although this method resulted in the "after" data, the RTOR permitted condition, being collected first, it was deemed preferable to selecting approaches where RTOR was prohibited and then removing the NTOR sign due to potential liability problems.

Following off-peak and peak counts at each of several intersections, five intersection approaches were selected. These approaches were selected because they had high RTOR volumes and, where appropriate, high pedestrian volumes across the approach. The volumes were determined through five minute/leg off-peak samples and 20-30 minute/leg peak period samples. Table 1 lists the selected approaches and study periods. Since each approach is studied during one, two, or even three time periods, there are a total of ten approach/time combinations called "sites" henceforth.

Select MOE's

A stopped time delay technique was used to measure vehicle delay savings due to RTOR during peak and off-peak periods. The method is based on the periodic sampling of the number of stopped or queued vehicles at an approach. An observer is stationed at or near the study approach. The number of vehicles stopped or between the first and last stopped vehicle in a queue on the intersection approach are counted at 15 second intervals. At the same time, the volume of the approach traffic is counted. The 15 second interval was selected to avoid repetitive sampling in the same interval of the signal cycle. All but two of the signals has a 70 second cycle (the other two were semi-actuated). From the sampled count data and the volume data, average delay per vehicle was estimated.

TABLE 1

SITE DESCRIPTIONS

Approach Name	Area Type	Number of Approach Lanes	1-HOUR TIME PERIOD STUDIED		
			A.M. Peak	Off Peak	P.M. Peak
State Street	CBD	2		12:00- 1:00 p.m.	4:00-5:00 p.m.
Stockton Street	CBD	2	7:30-8:30 a.m.	12:00- 1:00 p.m.	4:00-5:00 p.m.
Bellevue Avenue	Urban	2	7:30-8:30 a.m.	1:00- 2:00 p.m.	
US 31	Suburban	2		10:00-11:00 a.m.	4:15-5:15 p.m.
County Road 546	Rural	2	7:30-8:30 a.m.		

In addition, an indication of delay to pedestrians was measured by the number of pedestrians stopped or interferred with due to RTOR vehicles on an intersection approach as a percentage of the pedestrian traffic crossing the approach with the green. The pedestrian flow that would be impeded by RTOR vehicles will be those crossing with the green. Prior to the new regulation, this pedestrian flow was only impeded by vehicles turning into the leg they are crossing -- this can still occur. The only additional delay pedestrians can experience is that caused by RTOR vehicles out of the approach they are crossing.

Finally, the rate at which vehicles violated the RTOR law by failing to come to a full stop before turning was measured.

After the NTOR signs were installed, interim data was taken to determine the change in the rate vehicles violate the NTOR law by turning right on red. It was expected that the rate would drop initially and then level off. The NTOR MOE's were essentially the same as the RTOR MOE's except pedestrian volumes and pedestrian/vehicle conflicts were not measured.

Collect and Reduce Data

In October and November 1982, RTOR data was collected. One hour of data was collected on each of two weekdays for each of ten approach/time conditions or sites. On a typical day, four data collectors simultaneously collected stopped time delay, percent stopped, volume classifications, and pedestrian volume data.

The stopped time delay collector used a tape recorder to signal the 15 second intervals and recorded the number of stopped cars at each interval on a form. Sixty samples were collected in each of four 15-minute periods.

The percent stopped data collector recorded the total number of vehicles and classified them as stopped and not stopped on a form. This information provided the number of stopped and approach vehicles.

Then the data was reduced as follows:

1. Total delay = total number stopped x 15 seconds.
2. Average delay/stopped vehicle = $\frac{\text{total delay}}{\text{number of stopped vehicles}}$
3. Average delay/approach vehicle = $\frac{\text{total delay}}{\text{approach volume}}$
4. Percent of vehicles stopped = $\frac{\text{number of stopped vehicles}}{\text{approach volume}}$

Another observer classified the approach vehicles into left, right, and through movements when the light was green. During the red phase, the observer would also classify RTOR movements and through movements for the approach immediately to the left of the study approach. This movement was counted since the ability of a vehicle to make RTOR could be impeded by a high cross street movement. Also, where pedestrians were studied, the number of pedestrians impeded by RTOR vehicles was counted.

A fourth observer counted the number of pedestrians crossing the approach. From this number, the percent of pedestrians hindered by RTOR vehicles was computed.

Once the data was collected, the eight 15-minute samples were tabulated and summarized for each of the ten sites.

On January 13, 1983, NTOR signs were installed at all five intersection approaches. After erection of the signs, volume classification data was

collected during off-peak periods to determine how well and how quickly drivers were conforming to the new restriction. During February and March 1983, three one-hour volume classification samples were taken at each approach.

Finally, in March and April 1983, NTOR data was collected in the same manner as during the RTOR Study. Days of week and data collectors were matched up as closely as possible. The differences between the RTOR and NTOR stopped time would be reported as the delay savings/vehicle due to RTOR.

Results

RTOR Motorists Who Fail to Stop Before Turning

Overall, 40 percent of the drivers who turned on red failed to come to a stop before turning. See Table 2 and Figure 1 for site details. For the individual sites, the range of percent violations of the full stop provision of the RTOR law was from 29 percent to 62 percent of RTOR vehicles. For the data accumulated by time period, the highest violation rate occurred during the off-peak period (44 percent). It is interesting to note that a slightly higher percentage of motorists who violate the NTOR signs, do not come to a full stop before turning right on red (45 percent vs. 40 percent), when compared to motorists who do not stop when making a RTOR where it is allowed.

Motorists Who Violate NTOR Signs

From Table 2 totals, 11 percent of the approach (26 percent of the right turn) vehicles turned on red when RTOR was permitted. However, when

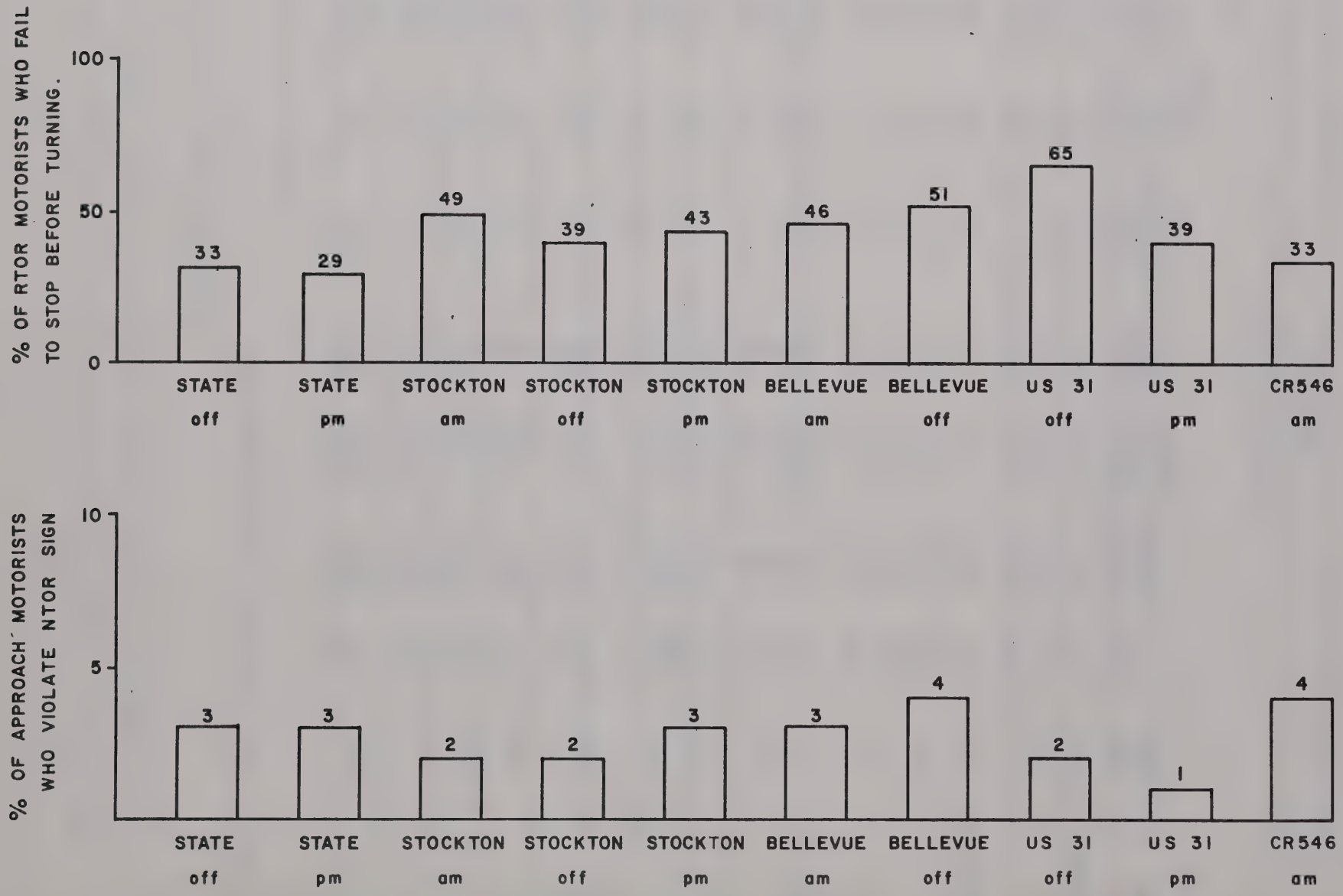
TABLE 2

RTOR AND NTOR DATA

Approach Name	Study[1] Hour	RTOR	Approach Volume	Right Turn Volume	RTOR Volume	% RTOR/ Approach Volume	% RTOR/ Right Turn Volume	Cross Street Volume	% RTOR Not Stopping
State Street	Off	No	772	360	20	3	6	288	30
		Yes	686	314	82	12	26	281	34
	P.M.	No	928	492	22	3	5	508	27
		Yes	986	576	143	15	25	493	29
Stockton Street	A.M.	No	454	101	10	2	10	149	60
		Yes	602	148	65	11	44	208	44
	Off	No	531	133	9	2	7	185	67
		Yes	559	143	24	4	17	195	29
	P.M.	No	722	286	19	3	7	391	42
		Yes	751	357	72	10	20	403	43
Bellevue Avenue	A.M.	No	413	177	11	3	6	542	36
		Yes	441	199	86	20	43	621	48
	Off	No	461	171	19	4	12	489	53
		Yes	393	177	50	13	28	469	50
US 31	Off	No	865	293	18	2	6	170	78
		Yes	787	285	85	11	30	146	62
	P.M.	No	1718	666	14	1	3	506	29
		Yes	1733	684	139	8	20	493	40
CR 546	A.M.	No	1056	366	38	4	11	258	45
		Yes	1128	416	123	11	30	280	29
Total	A.M.	No	1923	644	59	3	9	949	47
		Yes	2117	763	274	13	36	1109	40
	Off	No	2629	957	66	3	7	1132	57
		Yes	2425	919	241	10	26	1091	44
	P.M.	No	3368	1444	55	2	4	1405	33
		Yes	3470	1617	354	10	22	1389	37
TOTAL	ALL	No	7920	3045	180	2	6	3486	45
		Yes	8066	3299	869	11	26	3589	40

[1]Off = Off Peak; AM = Morning Peak: PM = Evening Peak.

FIGURE I RTOR AND NTOR VIOLATION RATES



RTOR was prohibited with NTOR signs, two percent of the approach (six percent of the right turn) vehicles turned on red. Since volumes and turning movements remained essentially the same, the change in RTOR utilization was due to the signs. Figure 1 illustrates the violation rate by site. Figures 2-5 demonstrate how quickly motorists obeyed the NTOR signs. By the time the NTOR delay data was collected, the violation rate had leveled off enough to minimize bias from motorist acclimation.

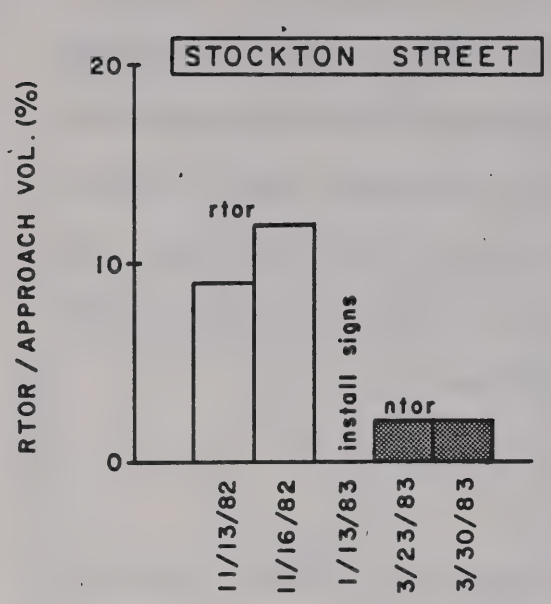
Vehicle Delay Savings with RTOR

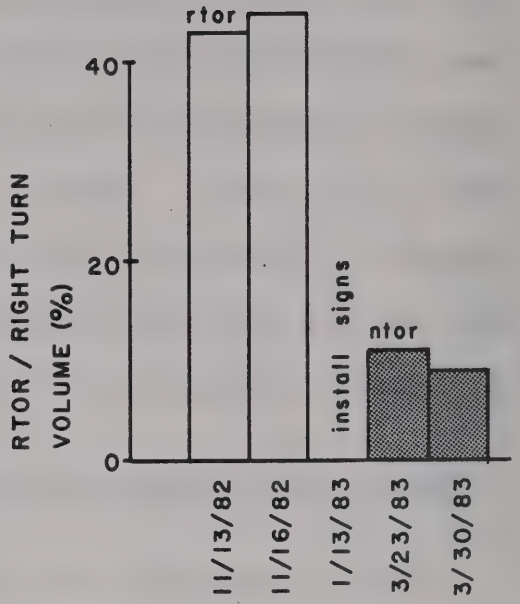
Figure 6 summarizes the vehicle delay savings due to RTOR. Overall, stopped vehicles saved 3.0 seconds/vehicle and approach vehicles saved 1.4 seconds/vehicle. Both delay savings were significant at a confidence level of 95 percent or better. A t-test (for 30 or more samples) was used to determine significance. The data was normal with the exception of a slight skewness of the NTOR delay/approach data. In both cases, 78 samples were used. The two percent increase in approach volume from the NTOR to the RTOR condition was not considered to be a factor affecting the delay savings. Therefore, the estimates of delay savings can be considered to be conservative.

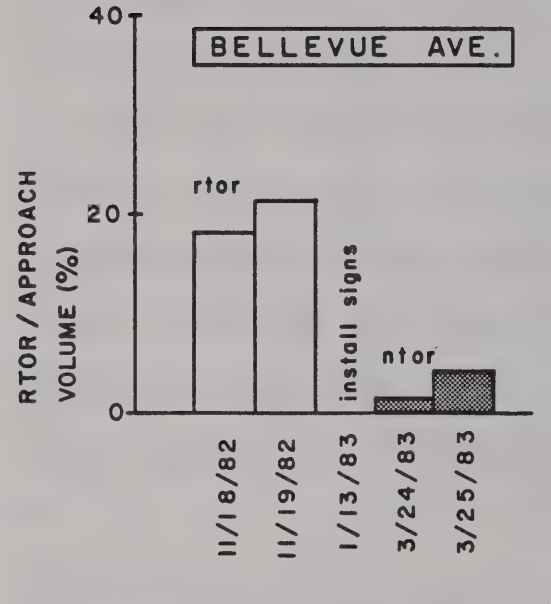
The individual sites (Table 3) were also tested for significance using a t-test designed for small samples (n less than 30) since eight samples were available from each site. A plot of the data for each site revealed that the data was essentially normal. The following delay savings can be attributed to RTOR at a significance level of 95 percent or better:

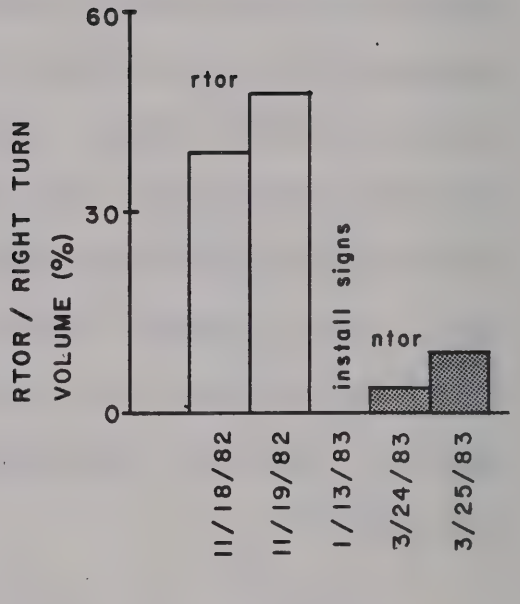
1. State Street - PM peak. Stopped and approach vehicle delay decreased 5.8 and 4.9 seconds/vehicle, respectively.

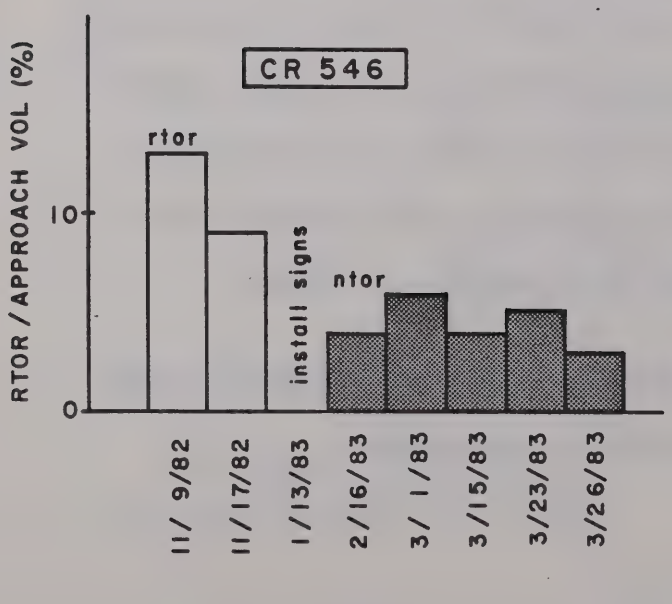
FIGURE 2. MOTORIST CONFORMANCE TO RTOR SIGNS - A.M. PEAK.











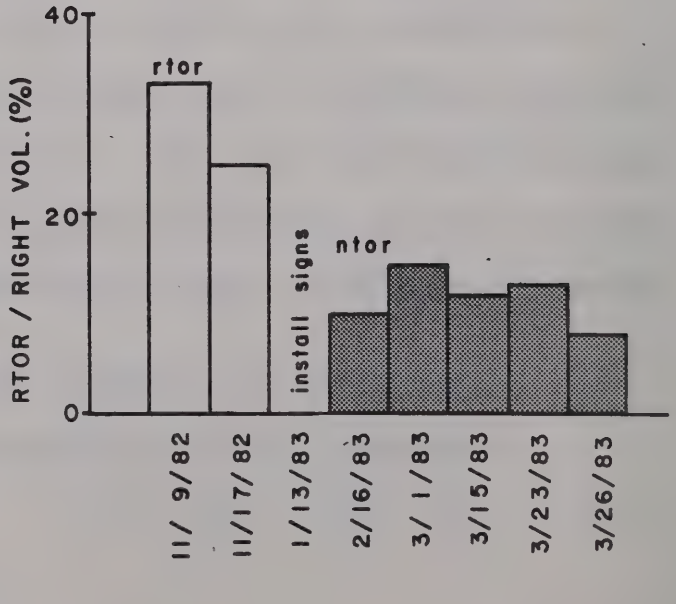


FIGURE 3 MOTORIST CONFORMANCE TO RTOR SIGNS - OFF PEAK.

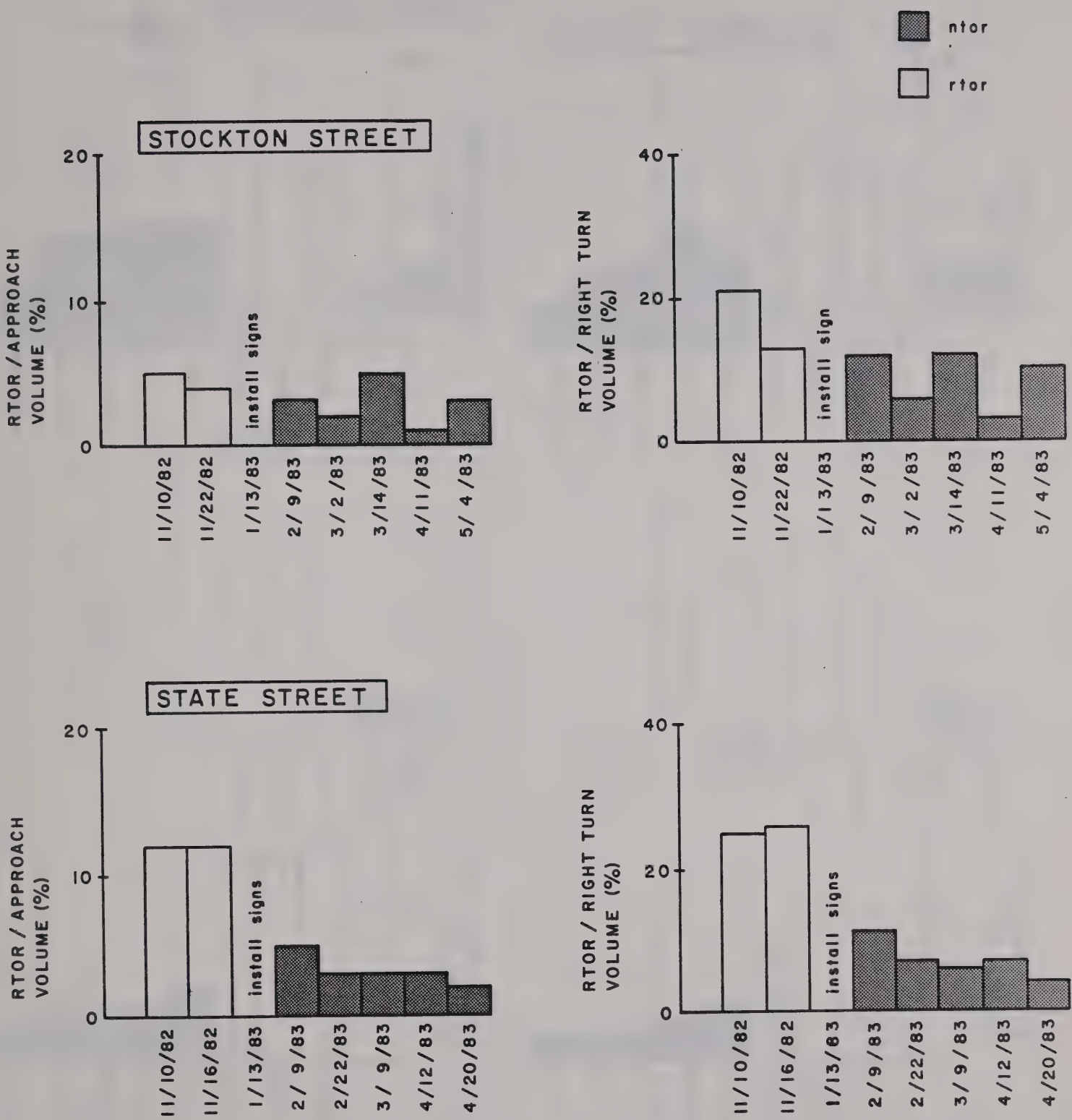


FIGURE 4 MOTORIST CONFORMANCE TO RTOR SIGNS - OFF PEAK

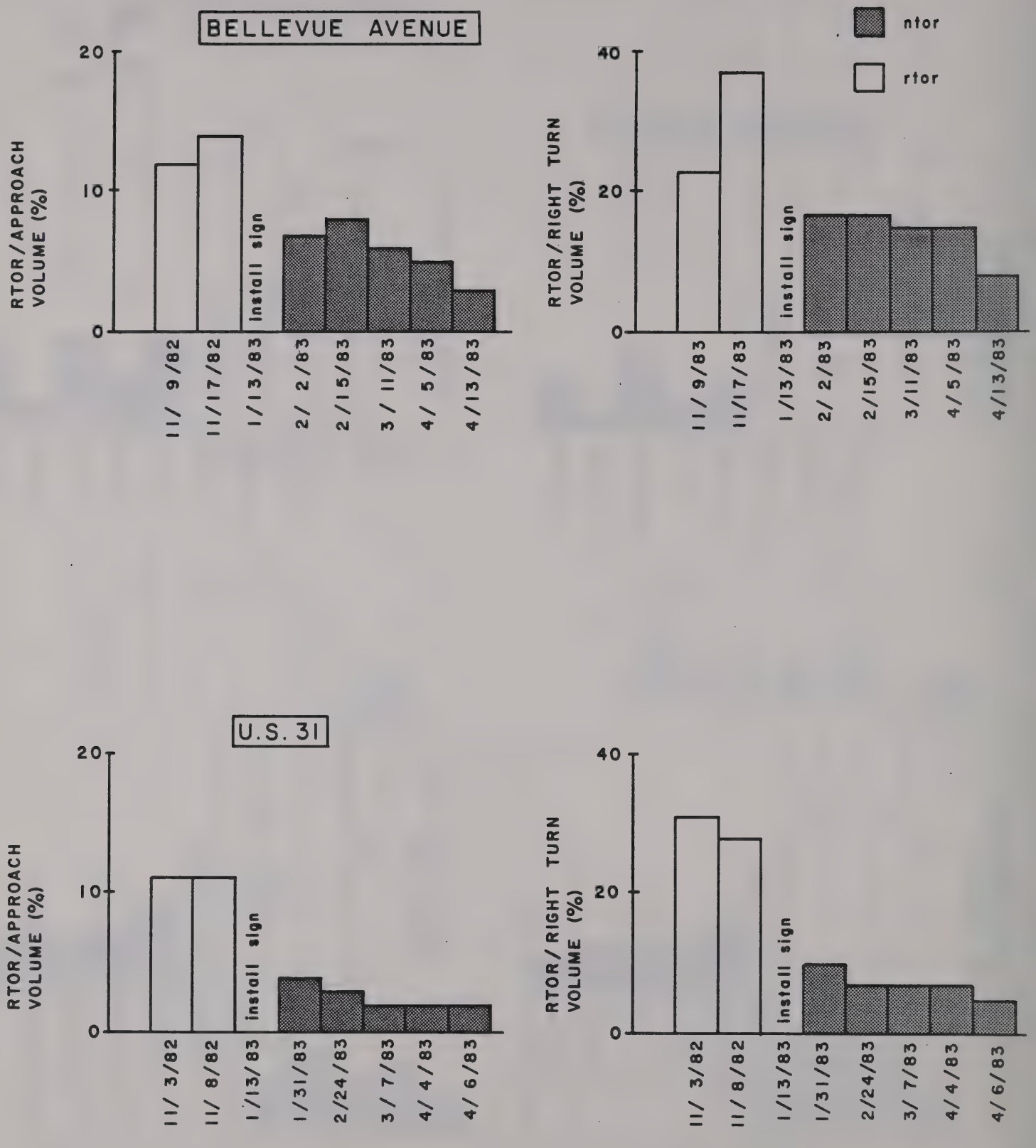


FIGURE 5 MOTORIST CONFORMANCE TO RTOR SIGNS – P.M. PEAK.

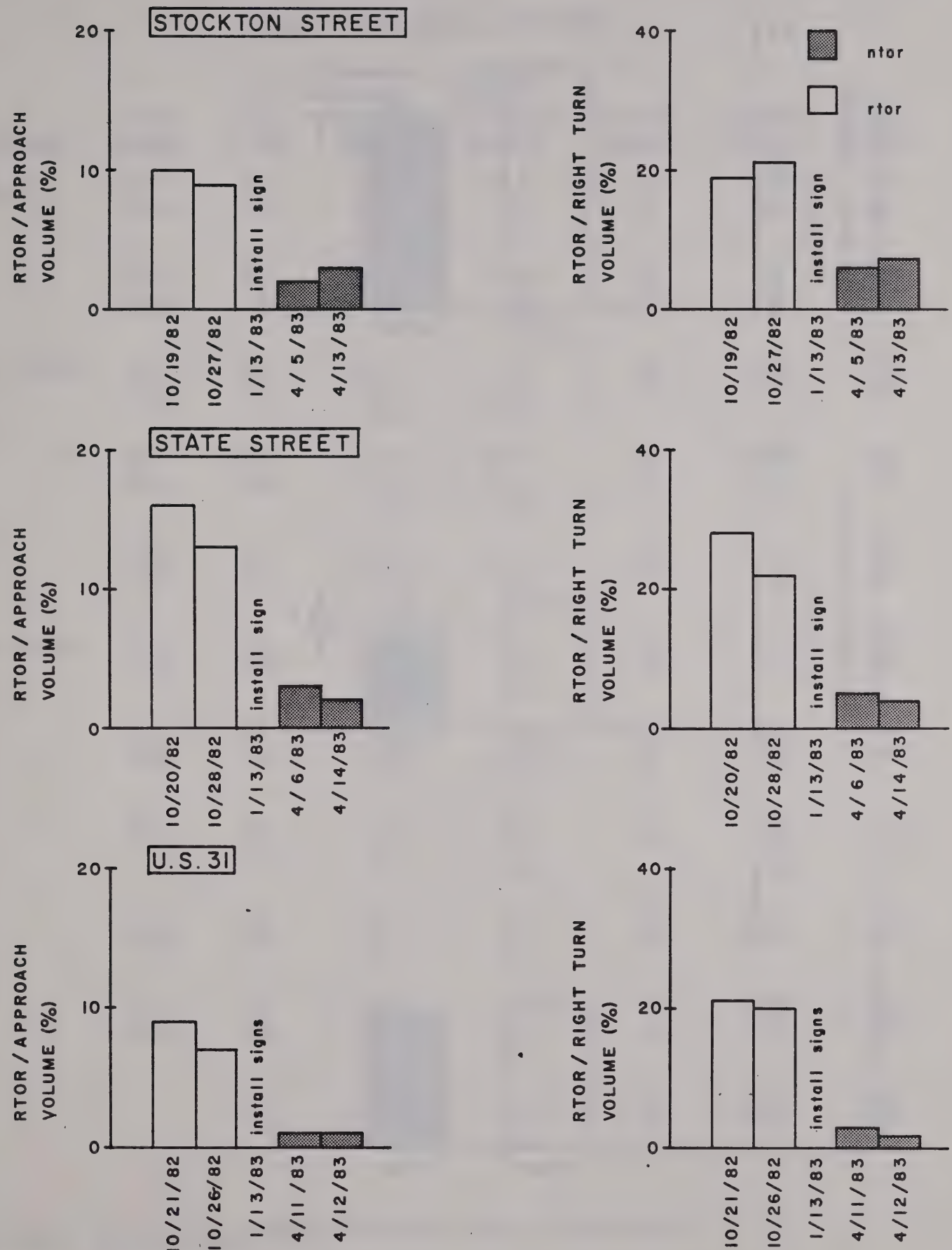
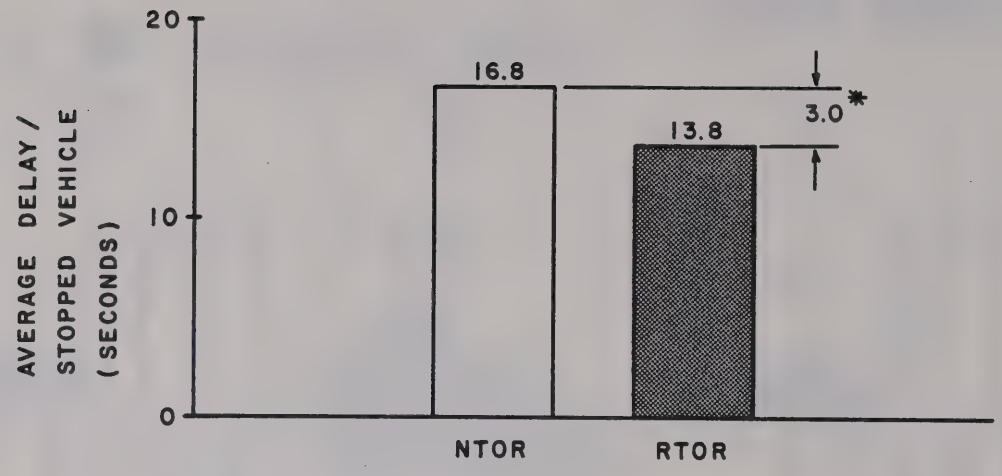
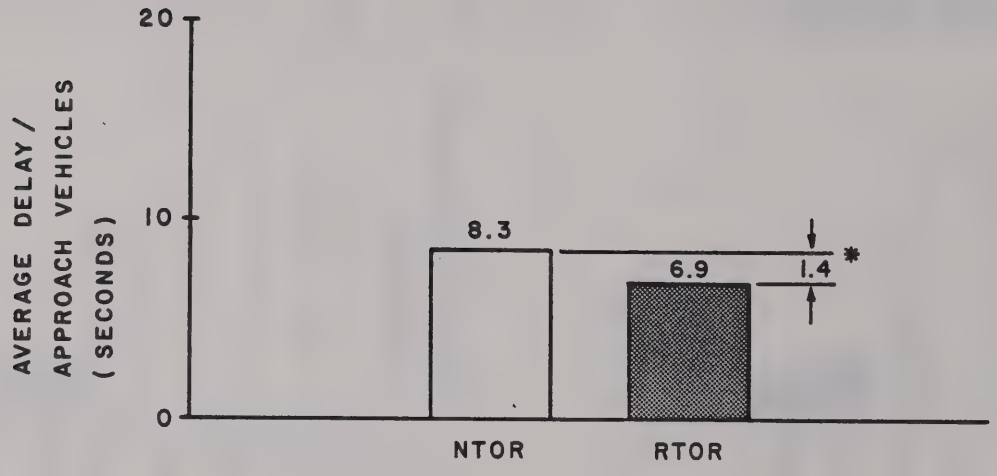
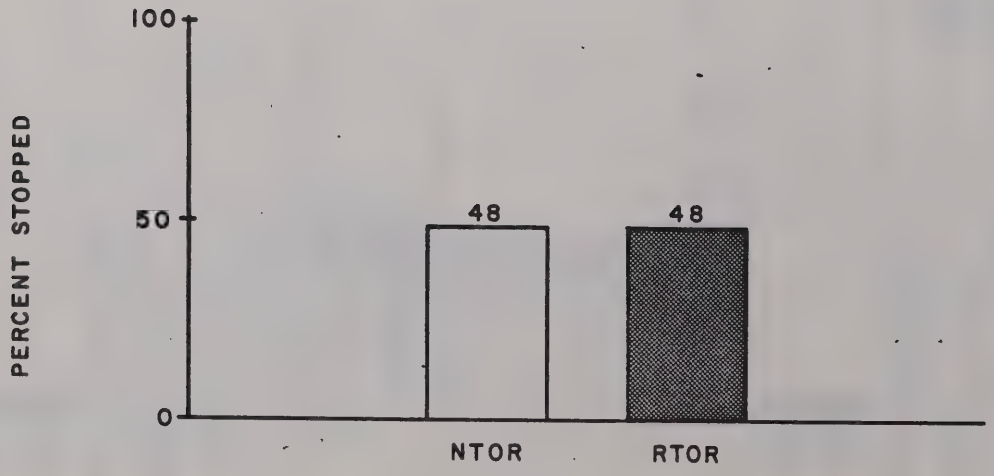


FIGURE 6 VEHICLE DELAY SAVINGS.







* SIGNIFICANT at 95% CONFIDENCE LEVEL

TABLE 3

VEHICLE DELAY SAVINGS WITH RTOR

Approach Name	Time Period	RTOR (Yes/ No)	Average Delay/ Stopped Vehicle	Average Delay/ Approach Vehicle	Percent Stopped	Approach Volume	Cross Street Volume
State Street	Off Peak	No	16.8	10.5	62	772	288
		Yes	12.9	9.4	73	686	281
			3.9*	1.1	*		
	P.M. Peak	No	23.2	14.8	63	928	508
		Yes	17.4	9.9	57	986	493
			5.8*	4.9*			
Stockton Street	A.M. Peak	No	17.6	8.0	45	454	149
		Yes	16.7	8.4	50	602	208
			0.9	-0.4			*
	Off Peak	No	20.3	10.1	51	531	185
		Yes	18.3	10.1	54	559	195
			2.0	0.0			
	P.M. Peak	No	21.0	10.2	51	722	391
		Yes	15.1	8.7	57	751	403
			5.9*	1.5			
Bellevue Avenue	A.M. Peak	No	19.9	9.8	49	413	542
		Yes	16.1	7.4	46	441	621
			3.8*	2.4			
	Off Peak	No	16.3	8.6	53	461	489
		Yes	11.6	4.8	40	393	469
			4.7*	3.8*	*	*	
US 31	Off Peak	No	10.1	2.7	27	865	170
		Yes	7.6	2.2	30	787	146
			2.5	0.5			
	P.M. Peak	No	12.9	5.9	50	1718	506
		Yes	14.0	5.3	39	1733	493
			-1.1	0.6			
CR 546	A.M. Peak	No	10.6	3.0	28	1056	258
		Yes	8.9	2.7	32	1128	280
			1.7	0.3			
TOTAL		No	16.8	8.3	48	7920	3486
		Yes	13.8	6.9	48	8066	3589
			3.0*	1.4*			

*Significant at 95% confidence level

2. State Street - off peak. Stopped vehicle delay decreased 3.9 seconds/vehicle. There was also an 18 percent increase in the percent of stopped vehicles, a result difficult to explain.

3. Stockton Street - PM peak. Stopped vehicle delay decreased 5.9 seconds/vehicle.

4. Bellevue Avenue - AM peak. Stopped vehicle delay decreased 3.8 seconds/vehicle.

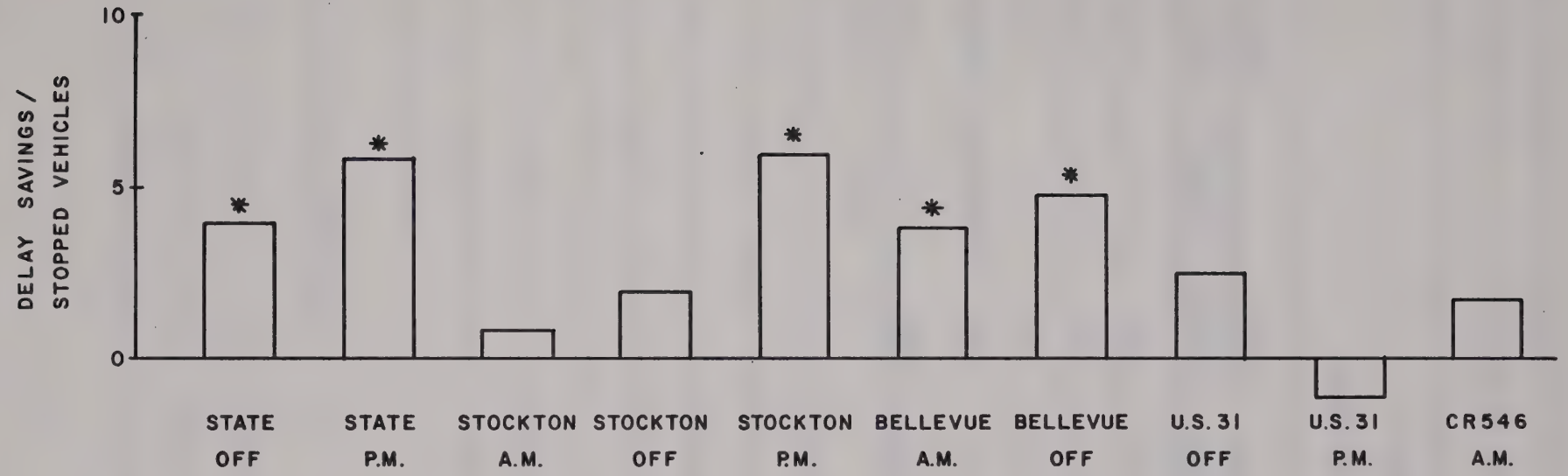
5. Bellevue Avenue - off peak. Stopped and approach vehicle delay decreased 4.7 and 3.8 seconds/vehicle, respectively. There was a corresponding 25 percent drop in percent of stopped vehicles, and approach volume decreased by 15 percent.

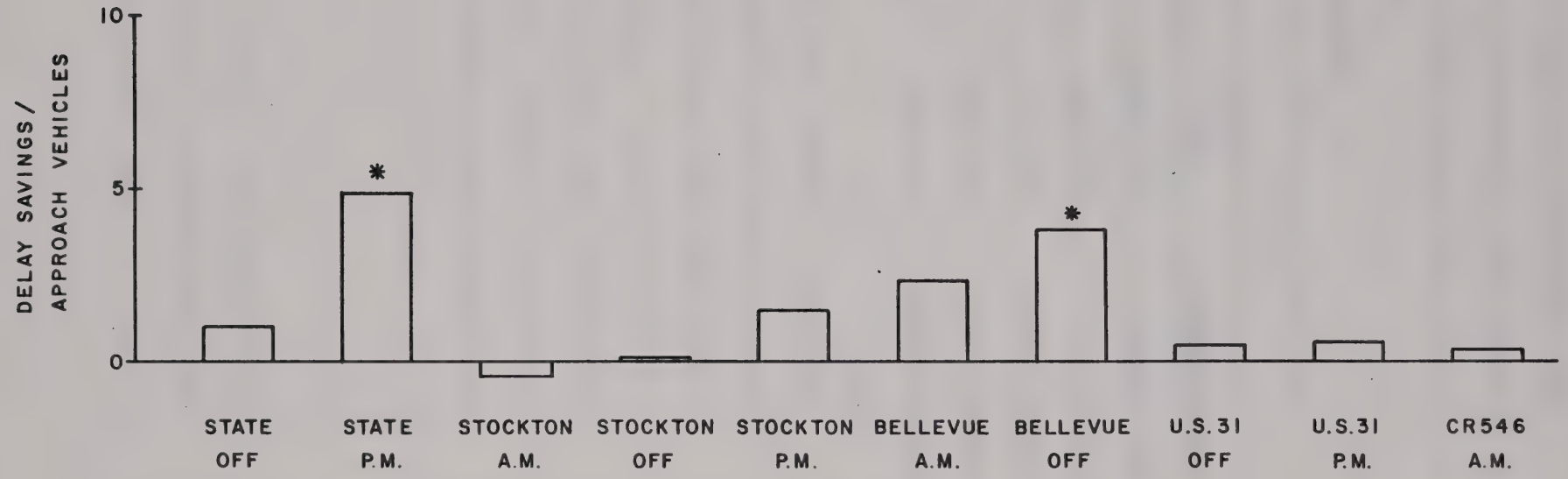
Figure 7 shows the delay savings for each site.

Pedestrian Delay

A total of 53 out of 986 or five percent of the pedestrians at five city CBD sites were interferred with, slowed, hesitated, changed their path, or actually stopped due to RTOR vehicles. The pedestrian flow impeded by RTOR vehicles was that crossing on the green. With no RTOR, the pedestrian flow was only impeded by vehicles turning into the leg they were crossing -- this can still occur. The only additional delay that pedestrians can expect is that caused by RTOR vehicles out of the approach they are crossing. Note Table 4 for specific pedestrian delay by site. It is apparent from the data that pedestrian/vehicle conflicts are determined primarily by the RTOR volume, not the pedestrian flow. This is clearly

FIGURE 7 DELAY SAVINGS WITH RTOR





* SIGNIFICANT AT A CONFIDENCE LEVEL OF 95% OR MORE.

TABLE 4

PEDESTRIAN DELAY

Approach Name	Peak Hour	RTOR Volume	Cross Street Volume	Pedestrian Volume	Pedestrian/ Vehicle Conflicts
State Street	Off Peak	82	281	118	14 (12%)
State Street	PM Peak	143	493	106	24 (23%)
Stockton Street	AM Peak	65	208	165	4 (2%)
Stockton Street	Off Peak	24	195	364	4 (1%)
Stockton Street	PM Peak	72	403	233	7 (3%)
TOTAL				986	53 (5%)

indicated by the increase in the percentage of pedestrians interfered with as the RTOR volume went up. The heaviest period of pedestrian flow had the lowest conflict rate (one percent) becuase the RTOR volume was so small (24).

The delay that the pedestrian experienced due to RTOR vehicles was very small. Usually the pedestrian had to hesitate, alter his path, or slow down because of a RTOR vehicle. The actual time of delay, although not measured, was obviously small. Rarely would a pedestrian completely stop due to a RTOR maneuver, usually it was the vehicle which stopped.

Comparisons with Other Studies

Motorists Who Failed to Stop Before Turning

In this study, 40 percent of the drivers who turned on red failed to come to a stop before turning. Another study (3) found that 11 percent did not come to a full stop. No other similar studies were found, and no explanation can readily be found for the difference. Reports were found in the literature (13,14) which measured the rate of stop sign violations as 31 percent to 88 percent of the approach volume. Some of this work was performed on low volume roads where a steady decline in full stops at stop signs was noted since 1935.

Motorists Who Violate NTOR Sign

Two months after RTOR was prohibited two percent of the approach (six percent of the right turn) vehicles turned on red. No reports were found in the literature which measured the violations of NTOR signs. In order to

determine what background level of NTOR violations exist in New Jersey, data was collected at 12 sites. At these sites, 0.3 percent of the vehicles made a RTOR where it was prohibited. That the violation rate is higher at the study sites (two percent) after the NTOR signs were erected is not surprising since at these locations motorists had been accustomed to making RTOR for many years.

One recent report [15] studied nine signalized approaches and measured the violation rate of the red signal at less than one percent. Most of these violations were vehicles going straight through the intersection immediately after the signal changed from yellow to red.

RTOR Utilization

When RTOR was permitted, 11 percent of the approach (26 percent of the right turn) vehicles turned on red. Other sources mentioned utilization rates as follows:

Report	RTOR/Right Turn
3	34%
1	20%
16	23%
9	19%

Vehicle Delay Savings with RTOR

Stopped vehicles saved 3.0 seconds/vehicles and approach vehicles saved 1.4 seconds/vehicle. According to one source [1], stopped vehicles saved 1.4 seconds/vehicle and approach vehicles saved 0.4 seconds/vehicle. Another source [16] found a 1.3 seconds/vehicle savings for approach vehicles.

Pedestrian Delay

Five percent of the pedestrians were interferred with, slowed, hesitated, changed their path, or actually stopped due to RTOR vehicles. Sources 2 and 3 indicated that pedestrians were not delayed by RTOR vehicles.

Estimation of Reduced Gasoline Usage and Pollutant Levels Due to RTOR

This study measured a delay savings per approach vehicle of 1.4 seconds when RTOR is allowed. As stated, this is in good agreement with results of other studies and, therefore, the estimation of reduced fuel usage and pollutant levels performed with the delay information should be a good "ball park" figure. The following information was used for this analysis:

1. Intersections involving a state highway with a county or local road carry 25,000 vehicles/day. (22,000 is the mean ADT on state roads and 3,000 is the mean ADT on county and local roads) (17,18,19).

2. Intersections of county and/or local roads carry 6,000 vehicles/day.

3. Seventy-five percent of the intersection approaches in New Jersey allow RTOR. This number was calculated from the 1978 survey of all signalized intersections performed by the Bureau of Traffic Engineering, New Jersey Department of Transportation.

4. An engine consumes 650 gallons of gasoline for each 1,000 vehicle-hours of idling (20).

5. The total number of signalized intersections in New Jersey is:

State Intersections	1,921
County and/or Local Intersections	4,617
TOTAL INTERSECTIONS	6,538

Fuel Savings at State Intersections:

1,921 Intersections x 75% Allow RTOR x 25,000 Vehicles/Day/Intersection

x 365 Days/Year x 1.4 Seconds/Vehicle x 1 Hour/3,600 Seconds =

5,100,000 Hours x 650 Gallons/1,000 Hours =

3,300,000 Gallons of Gasoline.

Fuel Savings at County and/or Local Intersections:

4,617 x 75% x 6,000 x 365 x 1.4 x 1/3,600 = 2,950,000 Hours

x 650 Gallons/1,000 Hours = 1,900,000 Gallons of Gasoline.

Total Gas Savings = 5,200,000 Gallons

1981 New Jersey Gasoline Usage = 3,500,000,000 Gallons

% Saved = 0.15%

5,200,000 Gallons at $1.25/Gallon = $6,500,000 Saved per Year.

The vehicle emission levels due to an idling engine are as follows (20).

Carbon Monoxide	2,430 lbs./1,000 vehicle hours
Hydrocarbons	160 lbs./1,000 vehicle hours
Nitrogen Oxides	50 lbs./1,000 vehicle hours

Based on the results of the delay study, 8,050,000 hours of idling time

were avoided each year due to RTOR. This results in the following reductions in pollutant levels per year:

Carbon Monoxide	9,800 tons
Hydrocarbons	650 tons
Nitrogen Oxide	200 tons

Discussion of Results

Allowing RTOR at a signalized approach effectively changes a traffic signal into a stop sign for right turning vehicles. Measures of stop sign violations found in the literature range from 31 percent to 88 percent of the approach vehicles. It should be noted that these violations are not limited to right turning vehicles only. This study found the violation rate for right turning vehicles at RTOR allowed approaches at 40 percent of the vehicles, ranging from 29 percent to 62 percent. Because it only encompasses part of the approach volume, the results of this work would seem to be similar to stop sign violations found in other studies. This could be interpreted as meaning that motorists have the same respect, or more truthfully, lack of respect for RTOR as they do for stop signs.

The violation of a traffic signal is another matter. This study measured the violations of NTOR signs, that is running a red light, as less than one percent of all vehicles where RTOR had been prohibited for years and about two percent where a change in the RTOR condition occurred months previously. In the literature, one study measured red light violations at less than one percent of all vehicles passing through signalized intersections. This high respect for the authority of traffic signals apparently has not been degraded by the implementation of RTOR. This and the fact that the stop provision of the RTOR law is violated to a similar extent as

the stop provision of the stop sign law suggests that the fears in some traffic engineering circles that allowing RTOR will cause a loss of respect for all traffic control devices is unfounded.

The delay savings measured in this study is slightly higher than in two other studies (1.4 sec. vs. 1.3 and 0.4 sec.). Since this study selected intersections with high RTOR volumes in order to minimize the time of data collection, the higher result is understandable. However, such a result may have caused the fuel usage and pollutant reductions to be a high estimate. There is reasonable agreement between the gasoline savings estimated in this study and previous work. McGee, et al [1] reported a gasoline savings of between 136 million and 187 million gallons of gasoline nationwide with an 80 percent implementation of RTOR. In 1976, the total gasoline usage for the United States was about 120 billion gallons. The potential savings estimated by McGee, et al is between 0.11 and 0.15 percent of the total which is similar to the estimate from this study.

Parker [3] estimated a fuel savings in Virginia of 3.6 million gallons which was 0.12 percent of that state's 1977 usage. Finally, Clark, et al [12] reported a combined gasoline savings in Alabama and South Carolina during 1980 of 5.9 million gallons. This constituted 0.15 percent of the total usage for the two states.

ACCIDENT STUDIES

Review of Past Literature

Since the mid-1970's when RTOR was mandated by the FHWA, a body of knowledge has been produced on the effects, benefits, and problems associated with RTOR. As anyone familiar with this literature already knows, these reports suggest vastly different effects on motorists, especially in the area of the RTOR-accident relationship. Some papers report a minimal or non-existent change in accidents while others show significant accident increases, both for vehicle-vehicle crashes and pedestrian accidents. A review and analysis of these past reports led this author to the conclusion that errors in their study designs make the results questionable. In this section, the errors in the methodology of past reports will be summarized and how the desire to avoid similar mistakes helped construct the design of this study will be outlined.

The weaknesses found in the study designs of previous reports can be grouped into nine types or categories. The use of a study design which incorporates one or more of these faults may have resulted in an incorrect relationship between RTOR and safety being suggested: The errors found are:

1. The aggregation of accident data from intersection approaches which allow RTOR with data from approaches which prohibit RTOR. If RTOR has an effect on accidents, whether it is to increase or decrease them, the use of approaches where RTOR is prohibited will tend to mask any changes which occur at approaches which allow RTOR.

In order to avoid this trap, this study dealt only with intersections which had all approaches allowing RTOR (the study group) and intersections which had all approaches prohibiting RTOR (the control group).

2. The selection of only part of the accident data at the intersection for study. This fault commonly took the form of measuring the effect of RTOR on right angle accidents, or RTOR accidents, or accidents involving right turning vehicles and excluding all other accident types from consideration.

Allowing RTOR at an intersection approach can result in accidents which do not involve either a right turning vehicle or a RTOR maneuver. If RTOR is to exhibit the benefits attributed to it, i.e., increased intersection capacity, decreased delay, fuel savings, etc., then it follows that the manner in which traffic approaches and traverses signalized intersections will change. It is within the framework of this change, not always involving a right turning vehicle or a RTOR vehicle that the potential for changes in traffic conflicts and accidents can arise.

This study collected all accidents at the signalized intersections. The accidents were classified by type and statistical analyses were performed on each type of accident to test for changes related to RTOR. If this study was wrong in the assumption that other accident types may be affected by RTOR, the accident analyses will show this and no more harm was done than the collection of extraneous data. If this study was correct in its assumptions, then the fact

that other studies failed to collect pertinent data will be established and their conclusions compromised.

3. The lack of use of a control group which prevents the disentanglement of historical accident trends from any accident change due to RTOR. Several studies used no control groups at all and reported that the change or lack of change in accidents at the intersections was due to RTOR. The implicit assumption in this type of study design is that accidents are stable from year to year. This is totally unacceptable since it is not possible to determine to what extent changes in land use, fuel availability, vehicle miles of travel, new road or traffic generator construction, vehicle design, population changes or the accident reporting system are responsible for any accident change, or lack of an accident change from one year to the next.

   This work selected a study group and a control group at which it can reasonably be said that the above factors will have similar effects. Therefore, any difference in the accident histories of the two groups can be attributed to the one difference between them - RTOR.

4. The use of improper control groups such as non-right turn accidents. This design assumes, without basis, that allowing RTOR will have no affect on any type of intersection accident other than right turn accidents. As previously stated, this study selected intersections at which all approaches prohibited RTOR as the control and collected non-RTOR accidents as study data.

5. The use of small numbers of intersections and small samples of accidents which requires very large changes in order to assign statistical significance. Our study counted more than 27,000 accidents at over 600 intersections during a seven year period.

6. The aggregation of data from roads with vastly different geometric and operational characteristics. This type of design dangerously assumes that RTOR will affect multilane, high volume, high speed approaches in the same manner as it affects single lane, low volume, low speed approaches. This study did not make that assumption but attempted to relate geometry, volume and speed to any accident change caused by RTOR.

7. The use of entire states as either the study or control group. This approach not only results in the errors outlined in #1 and #6 but has a further problem caused by the dates at which RTOR laws were enacted in each state. In the 70's, New Jersey had several changes in the accident trend. Before 1973, both total and intersection accidents had been increasing. Between '73 and '75, the accident trends leveled off and began increasing again after '75. It is likely that the oil embargo of 1973 was largely responsible for this phenomena. Which year a given state enacted their RTOR law, either around the time of the oil embargo or later, can change the apparent affect of RTOR. Our study avoids this problem by selecting the study and control samples interspersed throughout New Jersey. Oil embargoes, or any other factor, should affect the two groups equally.

8. The comparison of accidents during RTOR to accidents during RTOG. There is no theoretical basis for making such a comparison, unless for some inconceivable reason consideration is being given to replacing RTOG with RTOR. In order to determine the effect, if any, of the RTOR allowed condition, comparison must be made with the RTOR prohibited condition. This is precisely what our study did.

9. The use of accidents which occurred after RTOR implementation as before data, claiming a grace period is needed for driver acclimation to the change. The author agrees that such a grace period may exist but it should be accounted for by elimination of the period from the after data. Inclusion into the before data could seriously bias that information.

Study Design

To avoid the errors outlined in the previous section, the study design incorporated the following elements:

1. A large number of signalized intersections, randomly selected and split into two groups. The study group at which all approaches allowed RTOR and the control group at which all approaches prohibited RTOR.

2. Separation of the study and control groups into sub-groups by intersection geometry, traffic volumes and vehicle speeds.

3. Collection of three years of data before RTOR implementation and three years of data after, eliminating the first year after imple-

mentation (1977) as a driver acclimation period.

4. The analysis of all intersection accidents, not just right turn or RTOR accidents.

Selection of Study Variables

1. Controlled Variables - To be kept constant during the period of data collection in order to eliminate any effect a change in these variables would have on the dependent variable, accidents. The controlled variables include: traffic volume and movements, intersection geometry, signal characteristics, vehicle speed, land use, roadside obstacles, population density, and driver characteristics.

2. Independent Variables - To be varied in a structured way in order to establish the relationship between them and the dependent variable. The independent variables in this study are: the RTOR condition of the intersection approaches (either prohibited or allowed after RTOR implementation), and the time period, either before or after the implmentation of the RTOR law.

3. Dependent Variable - The factor to be measured for each condition the independent variables assume. The dependent variable in this study is accidents at the signalized intersections. Specifically, the accident statistics considered relevant were: collision type, pre-accident vehicle action, severity and time of day.

Statistical Analysis

The Chi-Square Test of Independence was employed in the analysis of the accident data. This was done by constructing a 2 x 2 contingency table

with the independent variables, RTOR condition and time period, as the classifications into which the data was assigned.

	Time Period: Before	Time Period: After
Allowed (Study Group)	a	b
Prohibited (Control Group)	c	d

Since these classifications are exhaustive and mutually exclusive [21], this type of analysis is appropriate.

The before and after time periods correspond to 1974-1976 and 1978-1980 respectively. The two RTOR condition classifications, "allowed" and "prohibited" are convenient but somewhat incorrect labels for these classifications. Certainly the study group, designated "RTOR allowed," did not allow RTOR in the before period since RTOR was prohibited statewide before 1977. An astute statistician might question the construction of the contingency table above since no data could be assigned to cell "a". No accidents could occur at RTOR allowed intersections before RTOR was allowed. This structural zero would seriously compromise the use of the Chi-Square Test in this analysis. However, when it is realized that "RTOR allowed" really means "intersections which had a change in RTOR condition, from prohibited to allowed, in 1977" and "RTOR prohibited" means "intersections which had no change in their RTOR condition in 1977," it becomes evident that no structural zero exists. Since the point of the entire study is to

see what effect the change in the RTOR law has on accidents, the classifications of the contingency table are proper, as long as the reader keeps in mind the true meaning of the short labels.

A 2 x 2 contingency table has 1 degree of freedom. The Chi-Square value, for 1 degree of freedom, which corresponds to a 90 percent level of confidence is 2.705. Values greater than this will be reported as statistically significant at the 90 percent (or greater) level of confidence and indicate that RTOR condition and the time period are not independent, but related. Values less than 2.705 will be reported as not statistically significant (N.S.).

The conclusions will infer from any lack of independence between the variables or classifications (Chi-Square values above 2.705) that the advent of RTOR has indeed affected accidents at intersections. The data itself will indicate whether this change is an increase or decrease in accidents and show its magnitude.

Discussion of Factors Which May Bias The Data

In conducting the study, it became apparent that deviations from the desired study design were unfortunately necessary. What compromises were needed, the reasons, and how they might bias the data and affect the conclusions are outlined in this section.

1. The study and control groups were not 100 percent pure, that is, some study approaches prohibited RTOR and some control approaches allowed RTOR. This deviation from the study design was caused by the fact that the information from which we determined the RTOR

condition of the intersections was a 1978 survey of all signalized intersections in New Jersey. Although, to the extent that we could check this information it was highly accurate, there were mistakes and changes in the RTOR condition after the survey. These errors or changes are responsible for the departures noted above. Field checks in 1981 of approximately 20 percent of the 612 intersections in the study resulted in the estimation that five percent of the approaches were incorrectly labeled.

The most likely result of this deviation is that any difference in the way accidents change at the study group relative to the control group will shrink. That is, if RTOR causes a decrease in accidents, having RTOR prohibited approaches in the study group and RTOR allowed approaches in the control group will cause the relative change in accidents to be smaller. Similarly, if RTOR increases accidents, the difference between the two groups will shrink when the groups are not 100 percent pure.

The results of this bias in the data will be an increased chance of incorrectly concluding that RTOR has no effect on accidents.

2. The fact that drivers do not always obey the No Turn on Red (NTOR) sign. In effect, this might cause a prohibited approach (a control approach) to behave like an allowed approach (a study approach) and thus be similar to the above situation (#1). If so, the bias to the data would be a tendency to shrink any real differences in accidents caused by RTOR.

However, a separate part of this study measured the violation rate of NTOR signs at less than one percent of the traffic. It is not expected that this small amount of violations will seriously bias the data.

3. The controlled variables outlined in the study design do not remain constant over the period of years and it is not within this project engineer's power (or anyone else's, for that matter) to see that they do. In consequence, there is the real possibility that accidents will change due to changes in these variables. However, since our study design calls for a large number of intersections in the study and control groups, since they were randomly selected and interspersed throughout New Jersey, changes in the controlled variables should cause equivalent changes in accidents for the two groups. With this assumption in mind, it is expected that no bias be added to the data because of changes in the controlled variables.

4. Contrary to the study design, we were only able to use two years of data before the change in RTOR law in New Jersey. The before period used in this study was 1975-1976. This deviation from the desired study design was caused by the fact that prior to 1975, New Jersey used a different accident data storage system. It was not considered worth the expense of writing a completely different set of computer programs to gather one additional year of data.

The use of three years of data before and after a treatment or change is a common method of accident analyses. The rationale

behind it is the desire to avoid the selection of a single, anomalous year when accidents behave differently than expected for reasons undetermined. If such a year is selected for either the before or after data, erroneous results could ensue. However, with the use of a control group, the need to use three years of before data is not considered as imperative as when no controls were used. Therefore, we feel that no important bias will be introduced by this deviation from our study design and that the conclusions will not be compromised.

5. Detailed geometric and operational information at 612 intersections was deemed too expensive to collect. However, the need to get some handle on the relationship between RTOR and accidents for different road types was considered highly important. A decision was made to split the study and control groups by which governmental agency has jurisdiction over the major road at the intersection: state, county or local. The assumption made in order to do this was that state roads have more approach lanes, higher traffic volumes, higher speed limits, and more accidents than county and local roads. Available data supported this assumption. Briefly, this data is:

   a. More than 50 percent of the approaches in the state group had 2+ lanes compared to less than five percent in the county and local groups.

   b. The average state road has an AADT greater than 20,000 compared to less than 5,000 for the average county and local road (17, 18,19).

c. More than half the state roads in the study had speed limits greater than 40 mph. It is assumed that the vast majority of county and local roads have speed limits of 35 mph or less.

d. Signalized intersections involving state highways have more than twice the accidents/intersection than county and local intersections.

These differences support the view that RTOR might have different effects on different road types. If this were not so, and the splitting was deemed superfluous, then the accident analysis should show each road type being affected in a similar manner.

Because of the differences between the state and county/local groups, the assumption is considered acceptable and any conclusions drawn from this analysis will not be considered compromised.

With the potential shortcomings of the application of the study design in mind, the accident analyses were performed. The results are presented next.

Results

Accidents at All Intersections

The first analysis considered accidents at all the intersections. The Chi-Square Test of Independence was applied to the total accident sample and to the following classifications of the accidents:

a. Severity

b. Type of Accident

c. Pre-Accident Vehicle Action

d. Time Period (Peak or Off-Peak)

e. Road Type

Table 5 lists the results of this analysis. For each classification, the relative change in accidents when comparing the study group to the control group is given. A (+) in this column means the study group (RTOR allowed) increased relative to any changes in the control group (RTOR prohibited). Conversely, a (-) means the study group decreased relative to any changes in the control group. The next column lists the X^2 value computed from the data and the final column states at what level of confidence it can be inferred that a statistically significant change has taken place. As stated in the study design, a Chi-Square value less than 2.705 will result in the conclusion that a non-significant (N.S.) change in accidents occurred.

As can be seen from Table 5, the following classifications had significant increases in accidents when RTOR was allowed: Total Accidents; Other Motor Vehicle Accidents, specifically, Angle Accidents; Accidents Involving Vehicles Going Straight Ahead; and most importantly, Accidents at Signalized Intersections Involving State Highways. This last result provides justification for our study design element which considered road type to be an important factor in this study. In comparison, the county and

TABLE 5

RESULTS OF ACCIDENT ANALYSES - ALL INTERSECTIONS

Accident Measure	Relative Change in Accidents - Before to After*	X^2	Level of Confidence
Total Accidents	+	2.904	90%
By Severity			
Fatal and Injury Accidents	+	1.052	N.S.
PDO Accidents	+	1.630	N.S.
By Type of Accident			
Other Motor Vehicle Accidents	+	3.059	90%
a. Same Direction	-	0.024	N.S.
b. Angle	+	3.469	90%
c. Head On	+	0.171	N.S.
d. Left Turn	+	1.573	N.S.
Pedestrian Accidents	+	0.161	N.S.
Pedalcycle Accidents	-	2.121	N.S.
Fixed Object Accidents	+	0.909	N.S.
By Pre-Accident Vehicle Action			
Going Straight Ahead	+	7.656	99%
Making Right Turn	+	2.171	N.S.
Making Left Turn	+	1.725	N.S.
By Time Period			
Peak Traffic Period	+	1.050	N.S.
Off-Peak Traffic Period	+	2.531	N.S.
By Road Type			
State Highway Intersections	+	10.219	99.9%
County Road Intersections	-	0.164	N.S.
Local Road Intersections	+	0.021	N.S.

* + Means the study group increased relative to the control group.
  - Means the study group decreased relative to the control group.

local groups had non-significant changes in accidents. It can readily be seen that the Total Accident result depends on the composition of the intersections in the sample. Less state intersections in the sample could have resulted in Total Accidents not increasing by a significant amount. Since New Jersey is one of the most highly urbanized states in the country and since the traffic volume on New Jersey roads far exceeds the national average, it seems reasonable that other states with less intersections comparable to NJ state highway intersections would conclude that RTOR has had little or no effect in their state.

Accidents at State Highway Intersections

Table 6 lists the results of this analysis and the results are somewhat unexpected. There was a significant increase in Other Motor Vehicle accidents, again, Angle Accidents and a perplexing result, Fixed Object accidents increased significantly. No reasonable explanation has been found for this last result; it seems farfetched that driver behavior at intersections changed so radically when RTOR was allowed that run off the road accidents would be affected. However, the result is there and it remains an anomaly of the study which otherwise produced consistent findings. As in the previous section, head on, left turn, pedestrian and pedalcycle accidents had non-significant changes.

More interesting than the above, are the results in the severity and time of day categories. The analysis reveals that injury accidents increased significantly along with property damage only (PDO) accidents. This result is in opposition to past reports which concluded that very few injury accidents would be caused by RTOR. This evidence contradicts that

TABLE 6

RESULTS OF ACCIDENT ANALYSES - STATE HIGHWAY INTERSECTION

Accident Measure	Relative Change in Accidents - Before to After*	X^2	Level of Confidence
Total Accidents, State Int.	+	10.219	99.9%
By Severity			
Fatal and Injury Accidents	+	3.809	90%
PDO Accidents	+	6.319	95%
By Type of Accident			
Other Motor Vehicle Accidents	+	7.137	99%
a Same Direction	+	2.022	N.S.
b. Angle	+	7.672	99%
c. Head On	+	2.524	N.S.
d. Left Turn	-	0.432	N.S.
Pedestrian Accidents	+	0.352	N.S.
Pedalcycle Accidents	-	0.762	N.S.
Fixed Object Accidents	+	6.249	95%
By Pre-Accident Vehicle Action			
Going Straight Ahead	+	8.378	99.5%
Making Right Turn	+	6.151	95%
Making Left Turn	+	0.737	N.S.
By Time Period			
Peak Traffic Period	+	1.312	N.S.
Off-Peak Traffic Period	+	11.828	99.9%

*+Means the study group increased relative to the control group.
-Means the study group decreased relative to the control group.

idea and certainly will have an effect on any cost-benefit calculations performed in concert with RTOR studies.

More surprising yet is the result obtained when the accidents were categorized into peak and off-peak traffic volume periods. The bulk of the accident increase at state highway intersections occurred in the off-peak period with a non-significant change occurring in the peak period. An explanation for this unexpected finding will be offered in the Discussion section, following this outline of the Results.

Because of the peak/off-peak finding, a decision was made to perform the accident analysis again, this time studying state highway intersections by time period.

Accidents at State Intersections by Time Period

In the peak period, the only significant change was an increase in the number of accidents involving vehicles making a right turn (Table 7). On the other hand, as Table 8 shows, many statistically significant increases occurred during the off-peak period. These include: injury and PDO accidents, other motor vehicle accidents, both angle and same direction, fixed object accidents and accidents involving vehicles going straight, right and left. No changes were found in head-on or left turn accidents and insufficient data was available to test for changes in pedestrian and pedalcycle accidents.

The increase in same direction accidents justifies our assumptions that RTOR can affect more than right turn accidents only. That and the fact that the pre-accident vehicle action of going straight ahead increased

TABLE 7

RESULTS OF ACCIDENT ANALYSES - STATE HIGHWAY INTERSECTIONS BY TIME PERIOD

Accident Measure	Relative Change in Accidents - Before to After*	X^2	Level of Confidence
Peak Traffic Period			
By Severity			
Fatal and Injury Accidents	+	2.204	N.S.
PDO Accidents	+	0.054	N.S.
By Type of Accident			
Other Motor Vehicle Accidents	+	0.987	N.S.
a. Same Direction	+	0.238	N.S.
b. Angle	+	0.563	N.S.
c. Head On	+	0.717	N.S.
d. Left Turn	-	0.005	N.S.
Pedestrian Accidents	Insufficient Data for Applying Statistical Tests		
Pedalcycle Accidents			
Fixed Object Accidents	+	0.546	N.S.
By Pre-Accident Vehicle Action			
Going Straight Ahead	+	0.810	N.S.
Making Right Turn	+	4.057	95%
Making Left Turn	-	0.151	N.S.

*+Means the study group increased relative to the control group.
-Means the study group decreased relative to the control group.

TABLE 8

RESULTS OF ACCIDENT ANALYSES - STATE HIGHWAY INTERSECTIONS BY TIME PERIOD

Accident Measure	Relative Change in Accidents - Before to After*	X^2	Level of Confidence
Off-Peak Traffic Period			
By Severity			
Fatal and Injury Accidents	+	2.751	90%
PDO Accidents	+	9.452	99.5%
By Type of Accident			
Other Motor Vehicle Accident	+	8.204	99.5%
a. Same Direction	+	2.923	90%
b. Angle	+	7.817	99%
c. Head On	+	0.827	N.S.
d. Left Turn	-	0.291	N.S.
Pedestrian Accidents	Insufficient Data for Applying Statistical Tests		
Pedalcycle Accidents			
Fixed Object Accidents	+	5.795	95%
By Pre-Accident Vehicle Action			
Going Straight Ahead	+	10.381	99.5%
Making Right Turn	+	2.767	90%
Making Left Turn	+	2.771	90%

*+Means the study group increased relative to the control group.
-Means the study group decreased relative to the control group.

significantly lends credence to the idea that allowing RTOR can change the way all motorists travel through intersections, not just right turning motorists.

County and Local Intersections

The accidents at intersections involving county and local roads only were analyzed in the same way that the intersections involving state highways were studied. The accidents were categorized by severity, type, pre-accident action and time period. These analyses yielded only one change which was significant at the 90 percent level of confidence, that is, left turn accidents during the off-peak period at intersections involving county roads. The consistency of the results when the data is divided by road type is striking. On a year by year basis, at intersections involving state highways, accidents increased dramatically where RTOR was allowed, when compared to intersections prohibiting RTOR. On the other hand, the changes in the study groups were similar to the corresponding control groups for the county and local intersections. This information can be seen graphically in Figures 8 and 9. The jump in accidents/intersection after RTOR was allowed in 1977 which occurred in the state highway study group is plain to see. No similar change occurred in the county or local groups. Figure 9 shows that the three control groups acted in a similar manner over the entire period of the study, as did the study intersections in the county and local groups. Only the state intersection study group stands out and indicates an increase in accidents attributable to RTOR.

Figure 8 also shows an interesting phenomenon. Whereas the effect of RTOR occurred as soon as the change took place in 1977, by 1981 the dif-

FIGURE 8

YEARLY ACCIDENTS PER INTERSECTION
BY ROAD TYPE

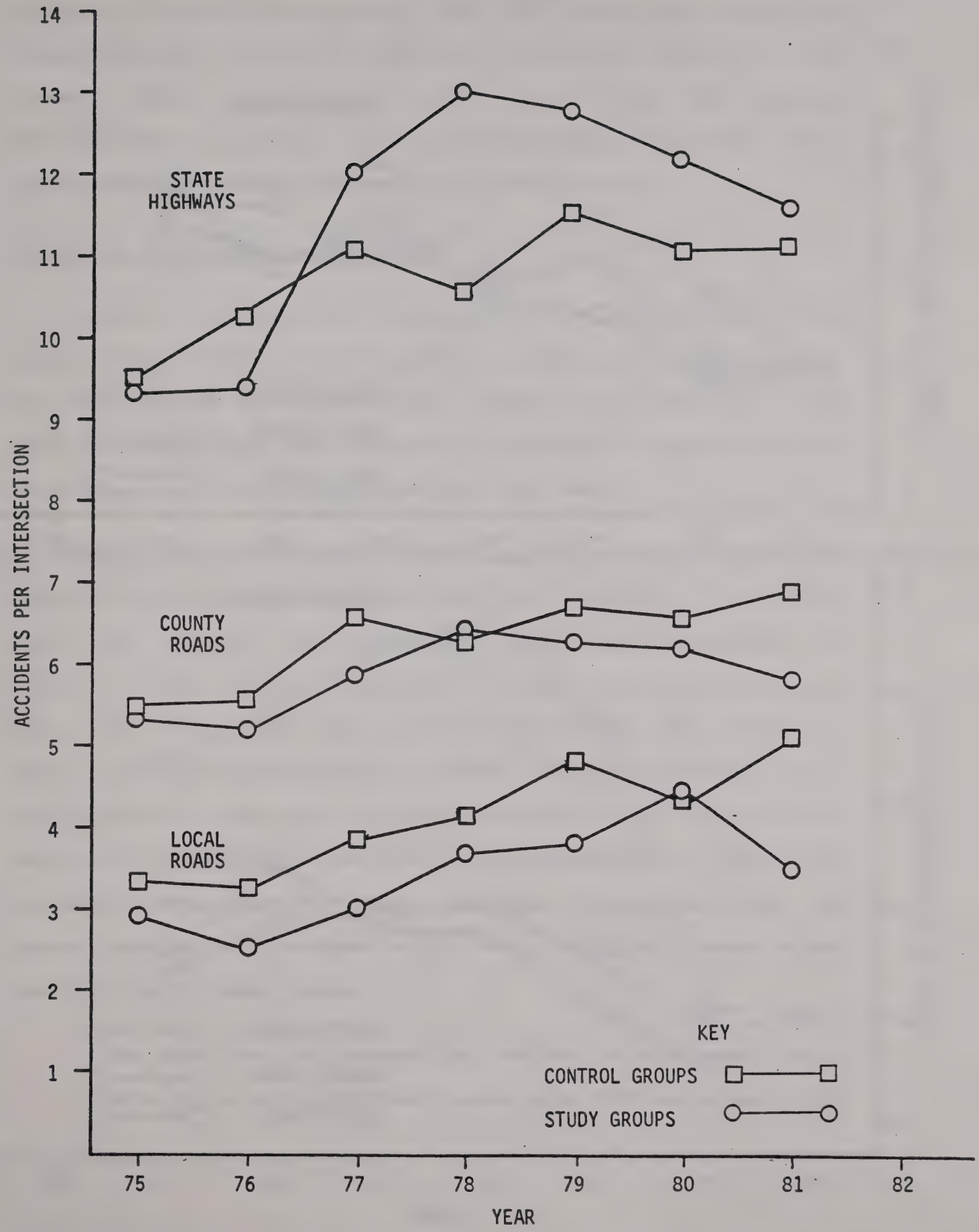
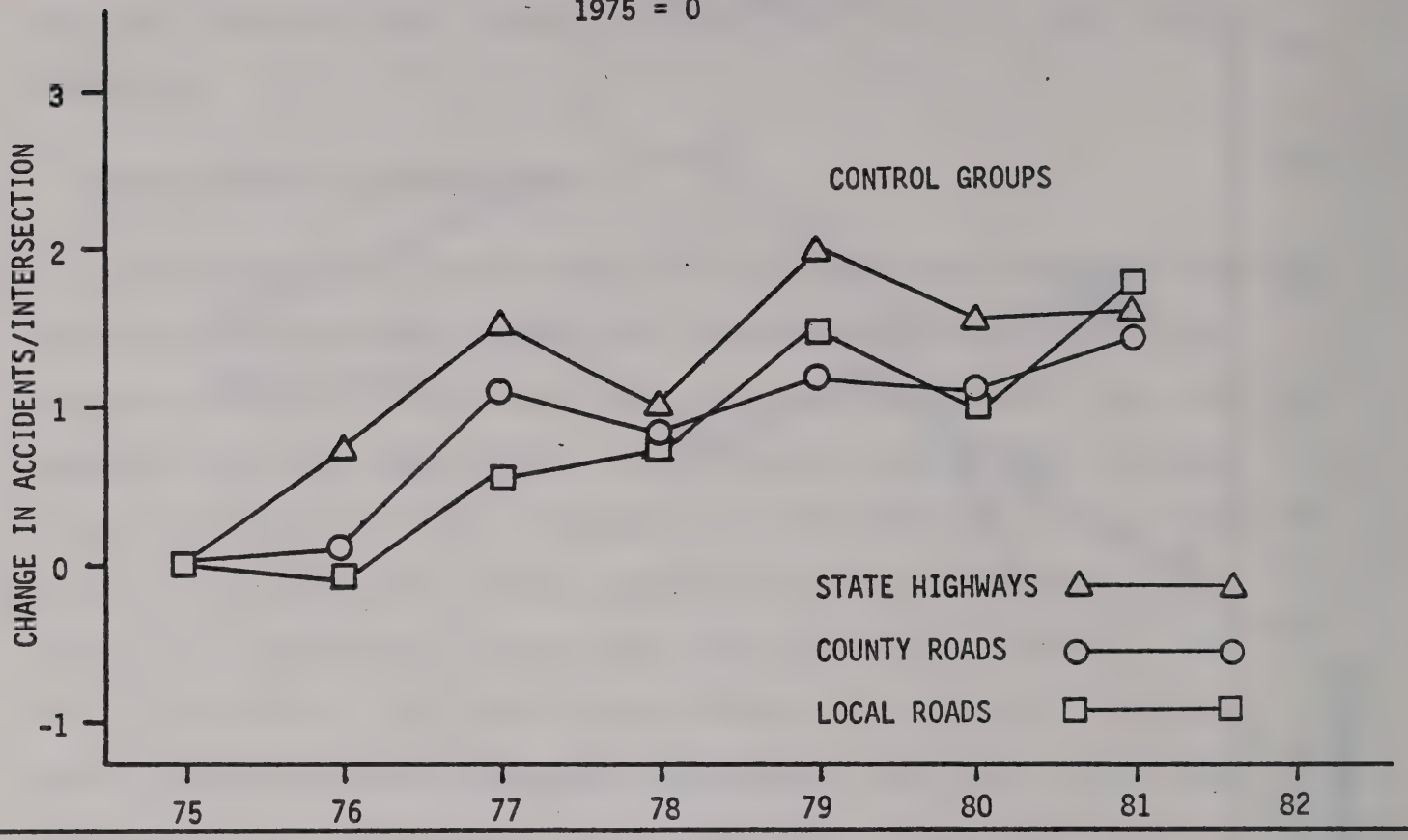
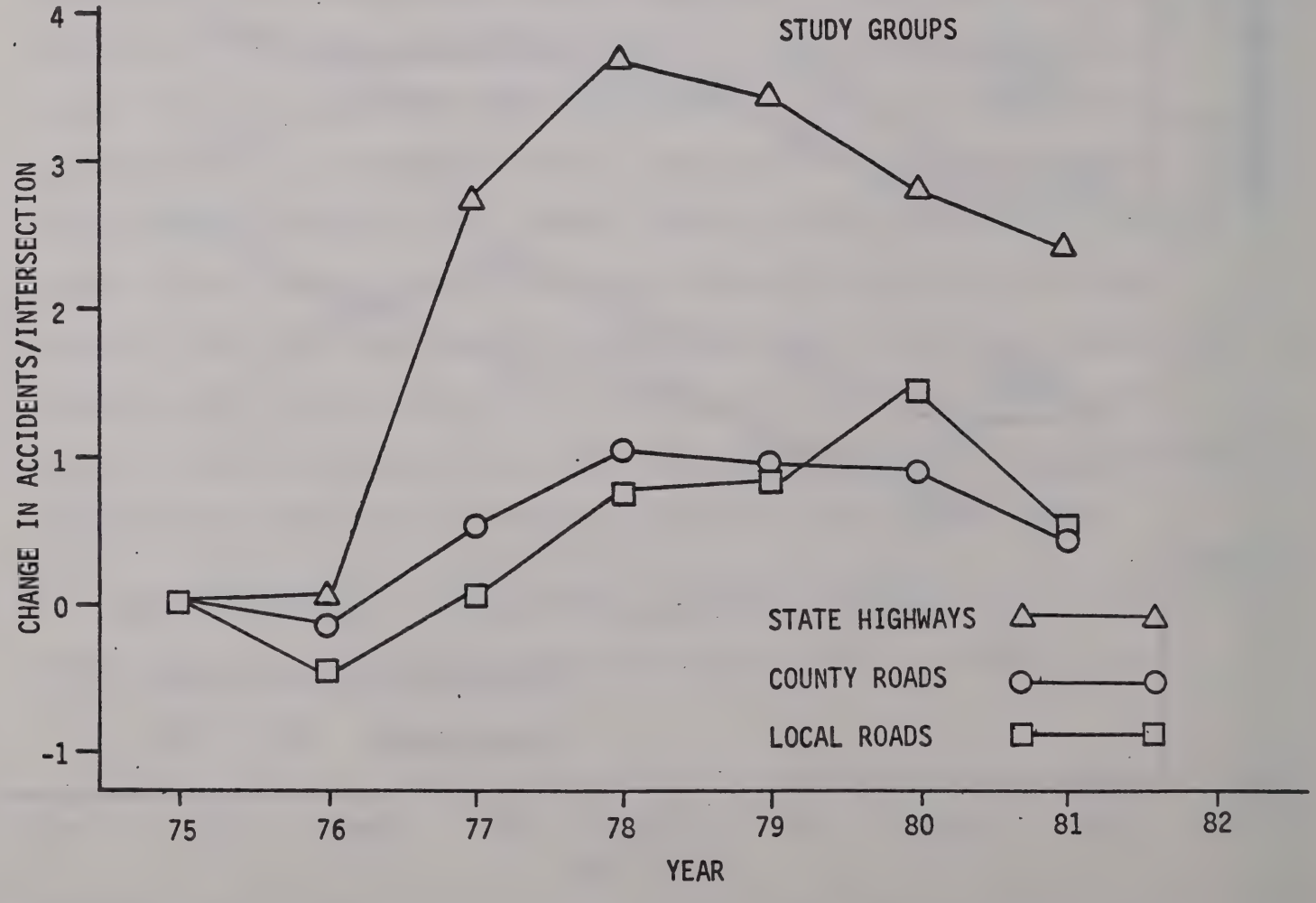


FIGURE 9

CHANGE IN YEARLY ACCIDENTS PER INTERSECTION

1975 = 0





ference in the accidents at the study and control groups for state intersections had lessened substantially. This might indicate that drivers have finally learned to negotiate intersections where RTOR is allowed in a safe manner. However, the acclimation period, where drivers became familiar with the RTOR law, appears to have lasted for years, during which a definite increase in accidents attributable to RTOR occurred.

Estimation of Accidents Caused by RTOR

Because of the results of the accident analysis with regard to road type, accident changes at intersections involving state highways will be the only type used in this estimation. Thereby, we are concluding, as the data so markedly shows, that no significant changes in accidents occurred at intersections involving only county and local roads.

Table 9 shows the accidents/intersection for the "before" and "after" periods by road type. The "before" period was 1975-1976 and the "after" period was 1978-1981. For the local and county road intersections, the study and control groups had increases of about 1 accident/intersection/year. The control group for the state intersections also increased by around 1 accident/intersection/year. However, the state intersection study group increased by more than 3 accidents/intersection/year. For this estimation, the assumption is made that the difference in the changes of accidents/intersection/year between the state intersection study and control groups can be attributed to RTOR. This assumption is deemed acceptable for the following reasons:

1. The study group for intersections involving state highways changed by a statistically significant amount after RTOR was allowed, when

TABLE 9

ACCIDENTS PER INTERSECTION BY ROAD TYPE

Road Type	Group	# Int. in Group	Acc./Int./Yr. Before	Acc./Int./Yr. After	Change Bef. to Aft.
Local	Control	104	3.29	4.58	+1.29
	Study	98	2.71	3.82	+1.11
County	Control	176	5.52	6.63	+1.11
	Study	119	5.25	6.18	+0.93
State	Control	38	9.92	11.08	+1.16
	Study	77	9.35	12.40	+3.05

Accidents at State Highway Intersections due to RTOR =

$$(C_{SG} - C_{CG})\ (I_A) + (C_{SG} - C_{CG})\ (I_P) =$$

$$\frac{}{2}$$

$$(3.05-1.16)\ (\ 1,338) + \frac{(3.05 - 1.16)}{2}\ (495) =$$

3,000/Year for the Period 1978-1981

C_{SG} = Change in Acc./Int./Yr., Study Group

C_{CG} = Change in Acc./Int./Yr., Control Group

I_A = Number of State Highway Intersections with All Approaches Allowing RTOR

I_p = Number of State Highway Intersections with Partial Allowance of RTOR, i.e., at some but not all approaches.

compared to the control group.

2. The number of intersections in the groups are large enough to cause accident changes due to other factors to be similar.

Estimating the statewide increase in accidents from this data is acceptable since the study and control intersections were selected randomly. The estimation was performed by multiplying the accident change per intersection attributable to RTOR (3.05 - 1.16 = 1.89) times the number of intersections involving state highways in New Jersey at which all approaches allow RTOR (1,338). In addition, one-half the accident change (1.89 - 2 = .945) was assumed to have taken place at those intersections which partially allow RTOR (495). This calculation totalled 3,000 accidents per year caused by RTOR at intersections involving state highways. Since the accident analysis revealed that injury as well as PDO accidents are affected by RTOR, the estimation technique was applied to these classifications. The 3,000 accidents per year yield 1,200 injury accidents and 1,800 PDO accidents caused by allowing RTOR.

COST/BENEFIT ANALYSIS OF RTOR IN NEW JERSEY

Accident Costs

Based on the estimation of accidents caused by RTOR, the following costs are presented:

1,200 Injury Accidents x $7,200/Accident = $8,600,000

1,800 PDO Accidents x $1,020/Accident = $1,800,000

Total Cost = $10,400,000

This represents the yearly cost to New Jersey motorists due to RTOR between 1978-1981.

The cost per accident figures were supplied by the National Safety Council (NSC, 1981).

Fuel Savings Due to RTOR

The delay portion of this study measured a delay savings per approach vehicle of 1.4 seconds when RTOR is allowed. This is in good agreement with results of other studies (1,10). Although RTOR appears to cause an accident problem only at intersections involving state highways, the delay savings and subsequently fuel savings, will occur at all intersections.

The percent gasoline savings (0.2 percent) is in good agreement with the savings estimated in the Voorhees report (1). That study reported a gasoline savings between 136,000,000 and 187,000,000 gallons of gasoline nationwide with an 80 percent implementation of RTOR. In 1976, the total gasoline usage for the United States was about 120 billion gallons. The potential savings estimated by McGee, et al was between 0.11 and 0.15 percent of the total compared to 0.15 percent for this study. Other studies estimated gas savings of 0.12% (3) and 0.15% (12).

Time Savings Due to RTOR

Several previous studies (1,9,12) have either suggested or actually reported a time savings due to RTOR which was an aggregation of the amount of time an individual driver saves each day over the entire population for

an entire year. One study (9) went as far as applying a monetary value to the aggregated time savings and reporting the amount as a benefit of RTOR.

Care must be taken before individual, daily time savings are added together to a large and impressive but potentially meaningless sum. It is not in the total where the problem may lie but in the individual, daily time savings. There is a threshold at which a time savings becomes a usable, desirable and perhaps a monetarily quantifiable amount. However, it is not cumulative over time or population unless the threshold is breached. For example, if one person saves one second, it is reasonable to say that no useful purpose can be achieved by such a savings. If one million people save a second, saying that one million seconds or 277 hours are saved is pointless since each person has only one second of time savings to use. Likewise, if the same person saves one second each day for a year, it is nonsense to aggregate the one second over the year and claim some larger total savings as meaningful. Any time saved in a single day must be spent that same day, it cannot be added to savings accumulated on other days. However, if the individual, daily time savings were one hour, then it is reasonable to assume that some value can be placed on such a savings. Furthermore, this savings can be added over the population and over time since it is not the time savings itself which is being accumulated but the actions and accomplishments that are performed during the time saved.

The idea that a time savings has no value until it is long enough on a daily basis to allow an individual to perform a needed or desirable action, is the basis of the time savings analysis due to RTOR presented herein.

Certainly the threshold for a useful time savings is between one second and one hour. No attempt will be made to determine what the threshold is, rather an average individual, daily time savings which might be experienced with RTOR will be estimated. If any actions, considered necessary or desirable can be accomplished in the amount of time saved, then the case for aggregating the information will be established. If such actions cannot be identified then the whole idea of time savings as a benefit of RTOR will be seen as a red herring, tantalizing but misleading.

For the purpose of estimating a daily time savings due to RTOR, the following assumptions will be made:

1. The average motorist drives 15,000 miles per year or about 40 miles per day.

2. Drivers encounter a signalized intersection on the average of one each mile.

3. Approach vehicles at a signalized intersection save 1.4 seconds if RTOR is allowed (from the Delay Study performed with this accident study).

4. Seventy-five percent of the signalized intersection approaches allow RTOR (from the Signalized Intersection Survey).

The daily savings per motorist under these conditions is:

40 intersections x 75% RTOR Allowed x 1.4 Seconds = 42 Seconds.

A second way of estimating the time savings uses the following assumptions:

1. and 2. The same.

3. A vehicle which makes a RTOR saves 15 seconds (half the red phase) on the average.

4. The same.

5. Forty percent of all vehicles approaching an intersection make a right turn (from the Delay Study).

6. Twenty-six percent of the right turning vehicles make a RTOR (from the Delay Study).

The daily savings per motorist under these conditions is:

40 Intersections x 75% RTOR Allowed x 40% Right Turns
x 26% of Right Turns Make RTOR x 15 Seconds
per RTOR = 47 Seconds

The reader is left to imagine all the wonderful things an individual can do with 47 seconds. This amount of time savings cannot, by any stretch of the imagination be considered of value. Therefore, time savings cannot be considered a benefit of RTOR.

Summary of Costs and Benefits Due to RTOR

1. A fuel savings of 1 to 1-1/2 gallons of gasoline per year per licensed driver in New Jersey is attributable to RTOR. At current gasoline prices, this amounts to a yearly savings of $1.25-$1.88 per driver each year.

2. A total fuel savings of 5,200,000 gallons per year, which is approximately 0.15 percent of the total New Jersey usage. This

savings each year would extend a 100 year supply of gas by 2 months.

3. The time saved by the average driver each day would be less than one minute with 75 percent RTOR implementation. This amount of time is too small to put any value on. Care should be taken not to fall into the trap of aggregating a large number of small, meaningless instances of time savings into a single, impressively large but equally meaningless total time savings.

4. The yearly accident cost due to RTOR was $10,400,000 during the period 1978-1981 while the savings due to the fuel conservation was $6,500,000 each year.

DISCUSSION AND SUGGESTED RESEARCH

From the results, the following scenario of a typical accident attributable to RTOR can be constructed:

a. It will occur at a multi-lane, high volume, high speed limit approach of an intersection involving a state highway.

b. It will most likely occur in the off-peak traffic period.

c. It will be an injury or PDO accident in the same proportion as all accidents at signalized intersections.

d. It will involve another motor vehicle and be an angle or same direction accident.

At first glance, there appears to be a contradiction between (a) and (b). The first statement seems to say that high traffic volume may be a cause of accidents attributable to RTOR while the second clearly indicates that during the high volume peak period, no relationship between accidents and RTOR exists. This apparent contradiction might be explained as follows: at low volumes cars making a RTOR and indeed all cars on an intersection approach will have a minimal number of opportunities to conflict with other vehicles. This is true for conflicts with vehicles in the same approach and for conflicts with cross street traffic. This condition will also reduce to a minimum the number of instances where a RTOR vehicle is impeded by a through vehicle in the right lane. Allowing RTOR during low volume times should, therefore, have little effect on accidents.

At very high volumes, those which usually exist during the peak period on state highways, the effect of RTOR on accidents might also be expected to be low. On a two lane approach, the chance of through vehicle blocking the right lane during the red phase certainly is greatly increased. Furthermore, large queues of vehicles on the cross street approach and increased pedestrian movements may reduce RTOR utilization causing the approach to behave somewhat like RTOR prohibited approach. Very high volumes may congest the intersections, lower vehicle speeeds and further reduce the opportunity for accidents.

In between these two situations, there appears to be a volume condition which is large enough to permit conflicts between vehicles to exist but not so large as to reduce RTOR utilization and cause congestion. This condition, which apparently exists at the state highway intersections during

the off-peak period is the most plausible explanation of the peak/off-peak result.

Perhaps the most interesting and hopeful result of the study is the apparent effect of time on the accident increase at state intersections. Figures 8 and 9 clearly show that the accident increase peaked in the second year after RTOR was allowed and it has been steadily decreasing since then. This decrease has been so large that there is a non-significant difference between the accidents before RTOR and the accidents during 1981. Every other year, including 1977 had an increase in accidents which was significant at the 90 percent level of confidence or greater. An important extension of this study would be to collect the accident data at the state highway intersections over the next several years to see if this decreasing accident trend continues.

This modification in accidents indicates that over a period of years, motorists have learned how to safely approach and traverse an intersection which allows RTOR. It does take some relearning on the drivers part. Vehicles approaching a red signal planning to turn right do not simply stop and wait for the signal change, they have to jockey for position as RTOR maneuvers are made. In this sense the approach acts like a stopped approach. In addition, vehicles planning to go straight through have new decisions to make when approaching a red signal, especially on a two lane approach. The desire not to block the right lane and, hence, prevent a RTOR maneuver may dictate a lane change to the left lane. On the other hand, any perceived advantage of being in the right lane in order to bypass a queue in the left lane may cause an opposite lane change. This may be an

advantage if enough cars in the right lane do make RTOR bringing the vehicle which made the lane change to the front of the queue. Perhaps the most relearning is required of through vehicles approaching on the green. Before RTOR, they generally did not have to be concerned with traffic on the cross street. With RTOR, they must watch for right turning vehicles from the approach to their right. In this way, the signalized intersection takes on some of the aspects of a stopped approach. When a traffic signal is placed where stop signs previously existed, the potential for accidents decreases due to the elimination of conflicts between vehicles on adjacent approaches. With RTOR, some of these conflicts return. In some ways the intersection behaves as if the stop signs still existed and it obviously takes motorists a long time to adjust to this situation on multi-lane, high volume, high speed approaches.

The proof of any scientific study is in its ability to be replicated. Although the belief that RTOR is a fait accompli is held by some in the transportation community, the potential disbenefits suggested by this work are sufficient to warrant further studies, both in New Jersey and other states either to confirm or disprove the results. As previously stated, the accident data for the state highway intersections in the study could be collected over the next few years to see if the accident trend continues. Additional work could be performed to obtain a better understanding between RTOR, accidents and traffic volume, vehicle speed and number of approach lanes, since the design of this study did not allow the effect of these factors to be segregated.

The costs and benefits developed in this study are not favorable to the continued use of RTOR on multi-lane, high volume, high speed approaches.

Time savings have been exposed as a non-benefit. For the period 1978-1981, the accident costs exceeded the dollar amount of the fuel savings. However, this paper recommends the continued use of RTOR, even at the state highway intersections as long as the trend in accidents shown in Figures 8 and 9 continues. RTOR is entrenched in the public consciousness as a beneficial traffic control strategy and the perceived benefits regarding fuel and time savings, insignificant as they are, do sway public and perhaps professional opinion. To this engineer, the most important benefit of RTOR is the reduced irritation which motorists experience by not having to wait at signals. Although this benefit would certainly not justify any degradation in safety, the fact exists that after 3-4 years of accident increases, motorists seem to have finally come to terms with RTOR, we're over the hump. But -- maybe it never should have been allowed.

If this study fails to convince the traffic engineering community that RTOR is a live, controversial issue, worthy of further discussion, investigation and perhaps modification then it is indeed a failure. If, on the other hand, the study leads to an understanding that perhaps there was a rush-to-judgement about RTOR in the heat of the 1973 oil embargo and that care should be taken to identify <u>real</u> costs and benefits before allowing the quest for energy conservation to result in a degradation of safety, in this case, the work can be considered successful and significant.

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